

# RESEARCH ON THE EVALUATION METHOD OF DRIVER BEHAVIOR USING DRIVING SUPPORT SYSTEMS

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Paper Number 05-0353

## ABSTRACT

Driving support systems, such as Adaptive Cruise Controls and Lane Keeping Assists, are believed to change driving behavior. These changes allow drivers to ignore the tasks performed by the driving support system, which can cause dangerous driving circumstances. A few reasons can account for the increased danger. First, decreasing driving responsibilities can make a driver lazier, while increased driving tasks require a quicker and more accurate understanding of the system. Second, an observant driver may disagree with the system's assessment of a situation.

In order to solve these problems, it is necessary to observe driving behavior more closely, to clarify the decision-making process by using some indexes measured by drivers' signals, and to discover why a driver's behavior changes through traced indexes.

This study reviews one method of determining a drivers' thinking process. We chose the Low-Speed Following system as the driving support system model item. The Driving Simulator in the Japan Automobile Research Institute was used to conduct the experiments. The indexes measured were breaking reaction time, moving time of eye points, and subject information based on the indirect method of Situation Awareness.

As a result, our method illustrated the drivers' decision-making process, and the reason for drivers' using the driving support system was specified. Furthermore, we estimated the validity of driver behavior changing when using driving support systems.

## INTRODUCTION

Driving support systems control the vehicle for the driver, making driving easier and safer. When drivers use these systems, they change their driving style. Since these changes create two problems, we should judge the safety of these changes, before they are instituted globally. We applied Situation Awareness (SA), the method used to clarify the cause of plane accidents, to evaluate which of these changes were safe for drivers. The purpose of this research was to confirm that this method was able to evaluate driving support systems.

### Two Important Tasks and Problems

Figure 1 depicts a driver's style when using a driving support system. A driver should pay attention to the traffic environment, whether or not the system is being used. We call this task the "Environment Observing Task." Furthermore, a driver who is using a system is responsible for observing the system controls instead of performing some vehicle operations (controlling the throttle, pressing the brake pedal, and turning the steering wheel). We call this new task "System Observing Task." These two tasks are important for driving safely with driving support systems. Present driving support systems may sometimes not control the vehicle safely. The driver must operate his vehicle independently, if the system controls malfunction. The driver must therefore maintain awareness of other vehicles and his own vehicle through those two important tasks.

There are primarily two problems in this

new style of driving. One problem is that a driver may neglect one of these important tasks. A driver may not respond or the response may be delayed in serious situations when the system fails to control the vehicle safely. A driver who does not perform these two tasks may not become aware of serious situations. Since the support system relieved the driver from some vehicle operations, the driver was apt to assume that he or she could omit these two important tasks. This condition is called over reliance.

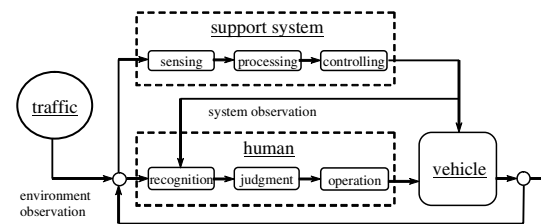
Another problem was that a driver failed to understand system conditions, and had a delayed reaction to or became confused in a serious situation. System Observing Task demands that a driver quickly understand the condition of the system, the operation by the system control, and the movement of their vehicle in the near future. A driver was in danger if he or she did not discover a system error or misunderstood the tendency of system control. This condition is called an error of system recognition.

### New Method of Evaluating Driver's Operation

There are two different causes of driver error, over reliance and recognition error. The effects of these problems are the same. Drivers do not take over control from the system or their taking control is delayed in serious situations. We cannot find the reason for a driver's operation and evaluate the driving support systems by just measuring a driver's reactions during serious circumstances.

We needed new methods for evaluating a driver's operation of a vehicle and driving support systems. Some systems have been developed for more than vehicle support. The method of Situation Awareness (SA) is used to clarify the causes of airplane accidents. The method indicates a pilot's awareness for the systems, copilots, controllers, etc. We show why the method is suitable for accounting for human recognition in the next chapter. We applied SA and found a new method that acquires a driver's thinking process in reaching an operation decision.

In this research, we clarified the basis of a driver's vehicle operation and evaluated the



**Figure 1. Relationship between driver and system operation, via two important observing tasks.**

driving support system by providing indexes to the driver's thinking process.

## SITUATION AWARENESS

Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future[1].

### SA Levels

Airplane pilots must process a great deal of system information and accomplish very complex operations. It is believed that many airplane accidents are related to lack of recognition[2]. In most of those cases, pilots were not able to grasp the environmental situation. This is called "Loss of Situation Awareness"[3]. The SA method breaks down why loss of situation awareness has occurred and clarifies and prevents plane accidents.

SA systematizes the process of operators' becoming aware of matters happening around them. SA investigates the recognition process in detail. The recognition process is divided into three levels[1,4]. Each of the three hierarchical phases will be described in more detail.

**Level 1 SA: Perception of the Elements in the Environment** - This is the first step in achieving SA. A subject at this level perceives the status, attributes, and dynamics of relevant elements in the environment. In a pilot's case, he or she would perceive elements such as aircraft, mountains, or warning lights along with their

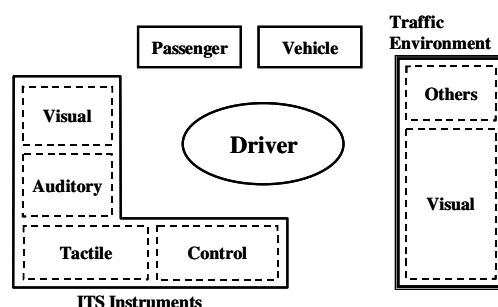
relevant characteristics (e.g., color, size, speed, location). Elements for vehicle operation with driving support systems correspond to what surrounds the vehicle, load condition, warning sounds, etc.

**Level 2 SA: Comprehension of the Current Situation** - Comprehension of the situation is based on a synthesis of disjointed Level 1 SA elements. Level 2 SA goes beyond simply being aware of the elements that are present by including an understanding of their significance in light of pertinent operator goals. Based on knowledge of Level 1 SA elements, the decision maker forms a holistic picture of the environment, comprehending the significance of objects and events. For example, a vehicle driver comprehends a vehicle's emergency brake from relative velocity and so on.

**Level 3 SA: Projection of Future Status** - The ability to project the future actions of the elements in the environment, at least in the very near term, forms the third and highest level of SA. This is achieved through knowing the status and dynamics of the elements and comprehending the situation (both Level 1 and Level 2 SA). For example, knowledge of the system limits and the sound of system alarms allow the driver to project that deceleration of the system would not be enough to avoid collision.

## SA Models

Operators recognize their environments through this three levels process. These levels are organized by elements. Furthermore, it is useful to classify the sources of these elements. This classification shows the connection between the operator and an element. Useful classification models have been proposed, including the SHELL Model (Hawkins)[5]. The authors have proposed the Transformed SHELL Model[6]. We altered the models to be suitable for vehicle driving. The Transformed SHELL Model interfaces between driver and environmental elements (See Figure 2). The traffic environment, condition of the driver's car (Vehicle), passengers and ITS instruments surround the driver. Using the Transformed SHELL Model, we are able to examine the



**Figure 2. Interface model for the analysis of situation awareness in driving (Transformed SHELL Model).**

problems encountered when thinking of the relationship between the operator and the sources of elements.

It is possible to verify the cause of a human error by using the three levels and the Transformed SHELL Model. It makes it easier to think about the most suitable systems for a driver.

## EXPERIMENTAL METHOD

We used a motion-based driving simulator[7] and arranged the following situation on a four-lane straight expressway. A host vehicle was equipped with a Low Speed Following system (LSF). The system followed another vehicle and controlled its own vehicle's throttle

**Table 1.**  
**Specifications of LSF in this study**

Scope of system support	+Stop the vehicle when following vehicle stops. +Start the vehicle when following vehicle starts.
Maximum deceleration	2.5m/s <sup>2</sup>
Time headway	1.6s
Stopping distance	3.0m
Turn off system control	+Driver applies the brakes +Turn off the switch

and brakes automatically. Table 1 presents the specifications of the LSF in this study. In this study, LSF started automatically when the following vehicle started. Deceleration by this system was limited to  $2.5\text{m/s}^2$ . This system was programmed not to follow safely so that a collision would occur if the driver did not apply the brakes at system limit condition.

### Experimental Event

Figure 3 illustrates the event in which driver behavior was evaluated. There were four vehicles in front of the driver's vehicle. Usually, these vehicles maintained a low speed and stopped very often, as if in a congested area. Vehicle A, Vehicle B and the driver's vehicle were in the same lane. Vehicle C and Vehicle D drove in the adjacent lane. The driver's vehicle followed Vehicle B.

At the beginning of the event, Vehicle C turned on the turn signal and started to cut in

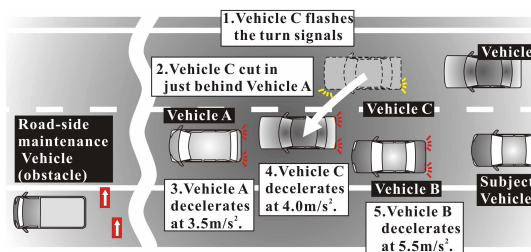


Figure 3. Illustration of the event.

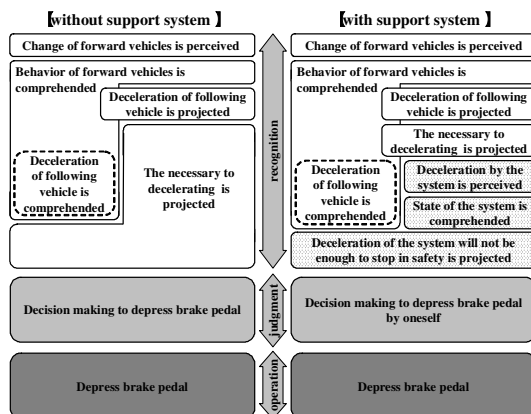


Figure 4. Driver's thinking process in the event.

between Vehicle A and Vehicle B. At the same time, Vehicle A decelerated to  $3.5\text{m/s}^2$ . Therefore, Vehicle C, just cutting in, decelerated sharply ( $4.0\text{m/s}^2$ ) and Vehicle B panic stopped ( $5.5\text{m/s}^2$ ).

### Decision-Making Process for Experiment Event

Figure 4 depicts the decision-making process for the driver during the experiment event. The driver's thinking progressed downward or sideways on the figure. The necessary SA elements in this event were relation to traffic environments and ITS instruments.

Figure 4 Applying indexes to the decision-making process. We were able to investigate the driver's operation from his or her thinking factors. Therefore, we measured three elements related to the driver's thinking, perceiving changes of leading vehicles, comprehending deceleration of following vehicles and projecting system limits. Perception was measured by eye-point reaction. The eye point would move to forward vehicles if the driver perceived change. Comprehending and projecting time were measured by asking drivers directly with video of their driving.

### Test Subjects

A total of twenty-six drivers, nineteen males and seven females, participated in this study. Their ages ranged from 23 to 53 years old, with an average age of 32.9 years. We divided subjects into three groups. The conditions of each group are shown Table 2. Group A subjects did not use the LSF system. Subjects belonging to Group B and Group C drove with the LSF system, but

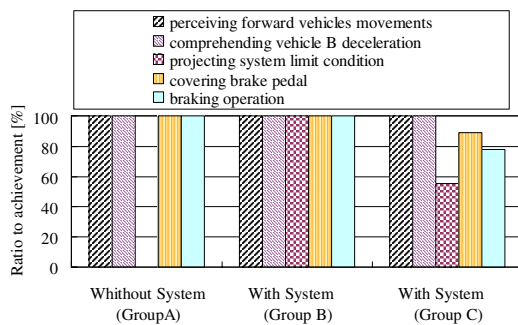
Table 2.  
Experiment conditions of groups

	LSF system	knowledge of system limit condition
Group A	Without	-
Group B	With	With
Group C	With	Without

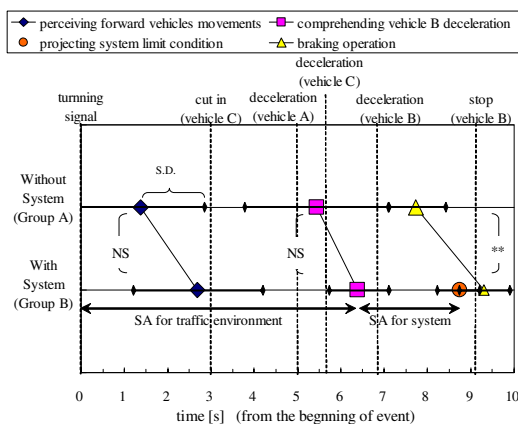
Group C was not instructed in the system limitations.

## EXPERIMENT RESULTS

We measured the driver's thinking elements and braking action. The thinking elements were perception of forward vehicles' change, comprehension of following vehicle's deceleration and projection of system limit condition, shown in the previous chapter. Braking actions were separated into covering and applying the foot to the pedal. The status of the driver covering the break pedal was measured before decision-making, while pedal operation was measured after decision-making.



**Figure 5. Ratio of achieving reaction / thinking.**



**Figure 6. Reaction time of drivers' thinking process.**

## Achievement of Thinking and Operations

Figure 5 shows the ratio of thinking and operations in each subject group. Bar graph values indicate the percentage of group members achieving to get thinking elements or operating the brake pedal.

**Perception and Comprehension of Leading Vehicles' Movement** - Perception and comprehension indexes were SA elements of the traffic environment. Those thinking factors were 100% for all three groups. This meant that all subjects achieved SA for the traffic environment.

**Projection for System Limit Condition** - Projection index measured in this study was SA elements for the system. It was projecting system limit condition. Percentage of Group B was 100%, but Group C, which had not been informed about system limits, achieved 55%. This meant that half of Group C subjects did not achieve SA for system by lack of system knowledge.

**Braking Actions** - All Group A and Group B subjects performed braking actions (covering and putting the foot on the pedal). Only Group C had subjects who did not brake. It was clearly caused by not achieving SA for the system.

## Thinking and Brake Operation Timing

All subjects belonging to Group A and Group B got thinking elements (SA for traffic environment and system) and operated the brake pedal. However, timing varied. Average times and standard deviation to achieve indexes are shown Figure 6. Horizontal-axis means passage of time from the event start (Vehicle C flashed turn signal). Incidentally, we permitted the comprehension time containing a driver's estimate for decelerating of Vehicle B. Therefore the driver comprehended Vehicle B's movement earlier than Vehicle B's actual decelerating time.

**Attention to Traffic Environment** - Driver formed SA for traffic environment between event start and achieving driver's comprehension forward vehicles movements. Two average times (driver perceived and comprehended forward vehicles movement) of Group A were shorter than those of Group B, but the results were not

significantly different. This suggested that using the LSF diverts a driver's attention to the traffic environment.

**Difference of brake operation time** - The average brake operation time in Group B was longer than that in Group A, and the result was significant.

On average, Group B subjects comprehended deceleration of vehicle B earlier than the average brake operation time in Group A. Consequently, drivers who were using the system paid attention to the traffic environment containing forward vehicles when drivers who were not using the system operated the brake pedal.

Driver formed SA for the system between comprehending deceleration vehicle B and projecting system limit condition. At the average brake operation time of Group A, Group B drivers were forming SA for the system. In other words, drivers who were using the system were observing the system (System Observing Task), when drivers who were not using system operated the brake pedal.

Therefore, braking latency generated by using the system under the study conditions was caused by the System Observing Task and was minimally influenced by lack of attention to the traffic environment.

### **Classifying a Decision-Making Pattern**

Group C had subjects who did not brake and crashed into the leading vehicle. Most of those subjects crashed without covering the brake pedal. However, some subjects covered the brake pedal, but never depressed the pedal. This suggested that a driver's decision-making process could be classified into several patterns. We patterned Group C's combination of achieved indexes shown in Table 3.

In Pattern 1, all indexes were achieved. This pattern fulfilled their two tasks (environment and system observing). Pattern 4 was opposite from Pattern 1. System Observing Task was neglected at Pattern 4. Subjects classified in this pattern crashed without brake actions.

At Pattern 2, drivers covered and operated

**Table 3.**  
**Subjects' reaction pattern**

	Perceiving of forward vehicles movement	comprehending vehicle B deceleration	projecting system limit condition	covering brake pedal	breaking operation
Pattern 1	○	○	○	○	○
Pattern 2	○	○	×	○	○
Pattern 3	○	○	×	○	×
Pattern 4	○	○	×	×	×

the brake, similar to actions in Pattern 1. However, they had not formed SA for the system because they failed to project system limits. Their brake operation occurred reflexively and the process to project the system limit condition was skipped.

In Pattern 3, drivers covered the brake pedal but did not depress the pedal. Those subjects said that they covered the brake pedal because they felt danger, but they did not know what they did at that time. Group C subjects did not know the system limits. Consequently, this event was an unexpected accident, and they were surprised at the automatic response (said Automation Surprise[8]).

This chapter shows that a driver's decision-making process may be different even if the operations are similar. There may thus be latent problems in reactions that looked best. Understanding the driver's decision-making process may help disclose those latent problems.

### **APPLICABILITY OF SA METHOD**

In this study, we verified the applicability of a new method to evaluate driver behavior and support systems. The SA method, which has been used for aircraft accidents, was applied for the evaluation. A driver's decision-making process was obtained by this method.

A driver's thinking timing was investigated using this new method. We were able to clarify how using a driving support system changed a driver's operation.

A drivers' decision-making processes could be classified into several patterns. These processes were different for each pattern even if their operations were similar. Latent problems may still be found in reactions that looked best.

Comprehending drivers' decision-making processes was useful in uncovering latent problems.

These results clarified driver behavior and decision-making processes. Therefore, we believe that this new method is applicable.

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